# Homeland security enforcement using novel terahertz technology

## –Final report–

This is the final report for Grant AOARD-05-4023. The report is organized as follows:

- Part 1: The initial plan of the research project;
- Part 2: The results obtained after the first one-year term;
- Part 3: Publication of the research results;
- Part 4: Use of the available budget.

On behalf of my colleagues I would like to thank AOARD for supporting our research; especially my thanks go to those people who first considered that our activity is worth the grant and who closely supervised our activity to ensure its advance.

## Part 1: Research project

The purpose of this project was to use our research experience for the advance of the terahertz technology to make it available for security applications. Specifically, for the period of this project (one year) we planned to improve our drug detection and identification method in the following ways.

### Preliminary filtering

We considered that a preliminary step in the mail screening process could greatly improve the practical application of the method. As most of the envelopes do not contain dangerous/illegal substances, we decided to find an easy (rapid) way to assess the presence or absence of a potential target. Only mail that is likely to need further investigation will go through a full terahertz scan for identification of chemical contents.

Our proposal for this preliminary step relies on the observation that usually the restricted substances are in form of powder. For the terahertz waves, powders produce the effect of scattering, which means that a beam entering the envelope does not continue its propagation straight ahead after passing through, but is caused to also disperse spatially into other directions. By detecting the scattering effect from each envelope we can have a yes/no signal to indicate the presence of a powder in that envelope. The time required to detect the scattered terahertz waves is very short, probably under a second per envelope.

We had made a few tests to check this principle, and the results showed that this new idea ccould be implemented to considerably shorten the screening time. Further experiments were required to find the optimum measurement configuration. Also, further consideration was needed for the cases when the restricted substance is not a powder, which may or may not require a different approach.

### Sensitivity and speed

Before the start of this project the detection limit of our method was at the concentration of approximately 3 $mg/cm^2$. Lower limits were thought possible by using improved sources and detectors. This could be especially useful in detecting bacterial spores (e.g. anthrax), which can be deadly even in extremely small quantities.

Another improvement direction was the decrease of the measurement time. Before this project started the time required for a 3000-pixel image was about 10 minutes. In a practical

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14. ABSTRACT
**The purpose of this project was to use RIKEN?s research experience for the advance of terahertz technology to make it available for security applications. The work improved drug detection and identification in packages.**

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implementation the number of pixels needed for imaging a regular envelope may be smaller than 3000; however, the time scale of minutes/envelope was still discouraging. By improving our sources and sensors we could reduce this time to a practical level.

## Part 2: Research results

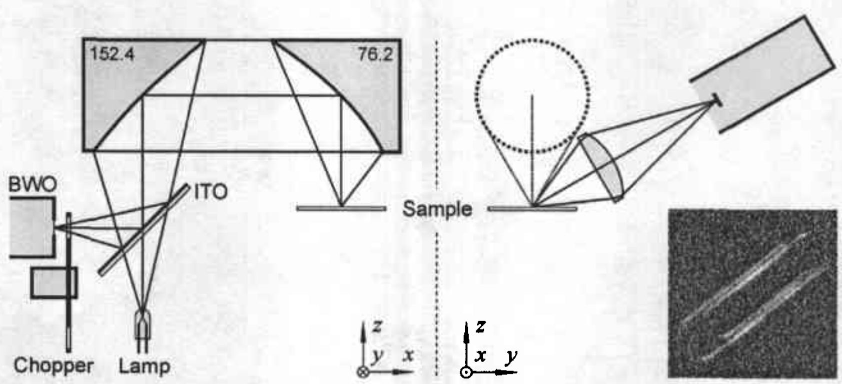
In short, the research had the following results:

1. The optical setup was optimized for sensitive measurements in scattering mode.
2. The detection sensitivity was improved by a factor of at least 1000.
3. The scattering characteristics of powders were investigated.
4. A new imaging mode (not part of the initial plan) was tested and demonstrated.

The sections below give details on each result.

### 1. Optimization of the optical setup

The optical setup is crucially important for the measurement results. The reduced scattering efficiency of powders and the presence of absorbing packaging materials make it hard to detect the scattered waves. We have tried several optical configurations and the one below showed good performance.




Schematic of the optical setup. The left-hand side of the figure shows the sample illumination system. The right-hand side, showing the collection of the reflected and scattered waves, is seen from a 90°-rotated direction; the dotted circle represents the parabolic mirror focusing the beam on the sample. For demonstration, the inset shows the THz image of a paper clip taken with this setup.

### 2. Improvement of the detection sensitivity

By a better choice of the detection scheme used we could increase the sensitivity of the setup. The figure below shows the significant improvement made possible by using a DLATGS sensor. The comparison is performed on a 500-yen coin, imaged in reflection with a usual lithium tantalate sensor and a DLATGS sensor. The signal-to-noise ratio and the dynamic range have greatly improved.

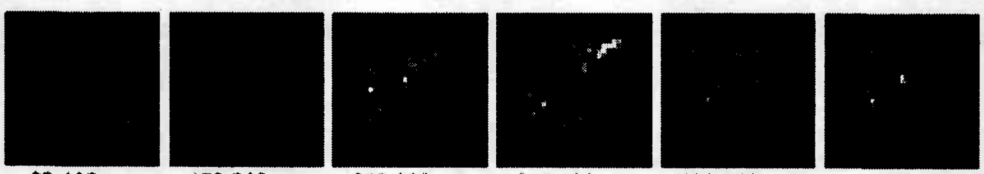
(a) (b) (c)

Images of a 500-yen coin [photograph in (a)] taken in reflection mode. The bright areas in the THz images (b) and (c) correspond to places on the metallic surface that direct the reflected waves toward the detector. As detectors we used a $LiTaO_3$ pyroelectric sensor for (b) and a DLATGS sensor for (c).

Our estimations showed that the sensitivity improved by a factor of at least 1000. This will allow the measurement of significantly better signals and a considerable shortening of the measurement time, almost by the same factor.

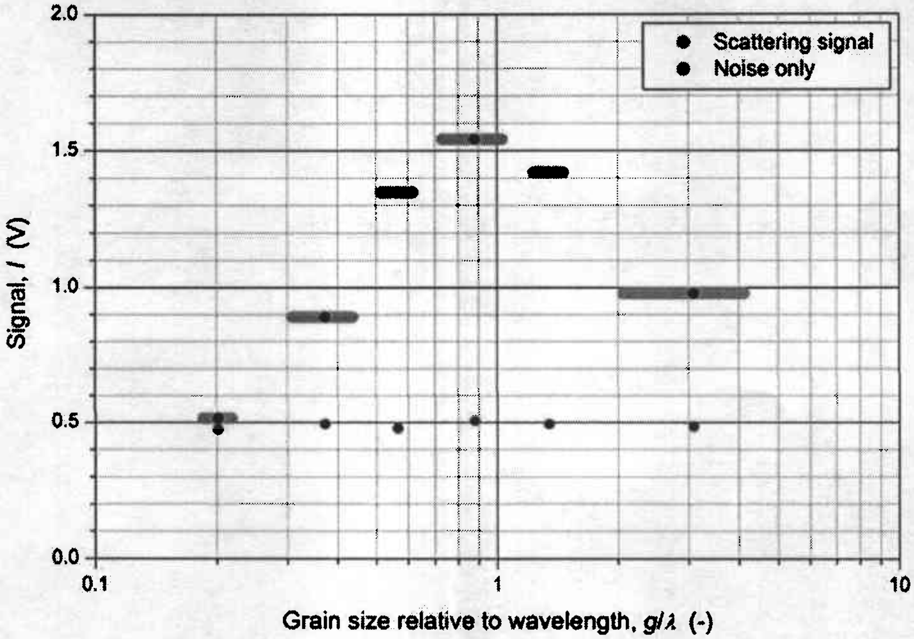
## 3. Analysis of scattering properties of powders

Powders of different grain size behave differently in the THz radiation, depending on the relationship between grain size and THz wavelength. We prepared a series of plastic bags (highly transparent to THz waves) and placed sucrose powders inside, with increasing grain size. The samples were imaged in scattering mode. It was confirmed that the best results are obtained with a wavelength close to the average grain size of the powder. This is essential in choosing the parameters for an actual application.



90-106 μm 150-212 μm 250-300 μm 355-500 μm 600-710 μm >1000 μm

THz scattering images of sucrose bags with different grain sizes at 617 GHz. The grain size range is written below each image.

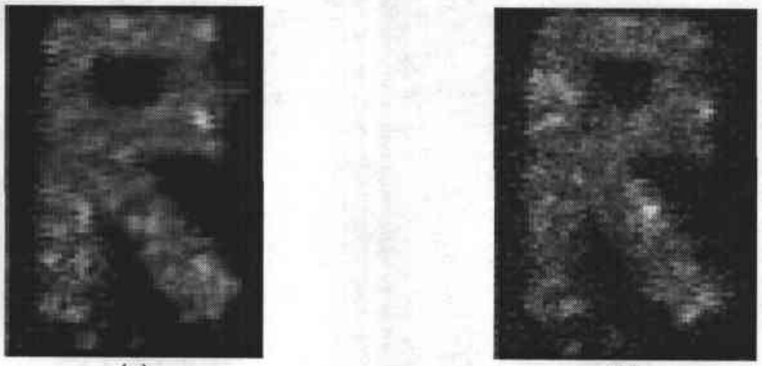



Plot showing the scattering efficiency as a function of the grain size given in units of wavelength ($\lambda$ = 486 μm). The horizontal bars represent the grain size range for each sample, and the gray dots below show the measured noise levels. "Signal" is an average value calculated from the images in the previous figure.

## 4. Imaging in scattering mode

Although not directly applicable in the mail screening application, imaging could become useful in other homeland security applications that may require knowledge of the position, shape and quantity of a powder or rough target.

The test sample was a target prepared from sucrose powder arranged in the shape of letter R, and imaged in scattering mode. For the second image below, the sample was covered by a sheet of paper to demonstrate the ability of THz waves to "see" through it.



(a) (b)

Sucrose powder arranged in the shape of letter 'R', imaged by collecting only the scattered radiation. The sample was imaged both as is, (a), and covered by a sheet of usual paper to simulate an envelope, (b).

## Part 3: Results publication

So far the results reported here were made public by participation in conferences, with the following talks:

▪ A. Dobroiu, K. Kawase, Y. Ogawa, M. Yamashita, and C. Otani "THz imaging applications (invited)," SPIE International Symposium on Microelectronics, MEMS, and Nanotechnology - Photonics: Design, Technology, and Packaging, Brisbane, Australia, December 2005

▪ A. Dobroiu and K. Kawase, "THz-wave sources and applications," NRC-IMS Biophotonics and Bioelectronics Workshop, Ottawa, Canada, August 2005

▪ A. Dobroiu and K. Kawase, "THz parametric sources and imaging applications (invited)," International School of Solid State Physics, 35th Workshop: Physics and Technology of THz Photonics, Erice, Italy, July 2005

If necessary, the contents of the talks is available in Microsoft PowePoint file format (*.ppt).

## Part 4: Budget use

This research was supported by several grants and funds. Specifically from the AOARD budget we made until now acquisitions in the following categories:

▪ Electronics: function generator, PCI-GPIB board, GPIB controller and cables, multifunction DAC, AC power supply, digital multimeter, etc.

▪ Optics: infrared mirrors, off-axis prabolic mirrors, etc.

▪ Various accessories and consumables.

From the second part of the budget we will pay the travel expenses for participation at conferences, fees for membership in scientific associations, and other expenses that will appear necessary in the near future.

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